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Assessment of the effect of No Stay, Bent Stay or Straight Stay when the Clothe the Soldier Rucksack is worn with the Fragmentation Vest

by

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Abstract

The Clothe the Soldier (CTS) load carriage system includes the Fragmentation Protection Vest (FPV) with Bullet Resistant Plates (BRP), Tactical Vest (TV), the Rucksack, and a Small Pack System which have been designed to be compatible. Loads carried in the CTS rucksack often exceed the officially recommended 25 kg and are reported to approach 45 kg. Under these conditions, optimizing load distribution onto the torso becomes even more essential. The purpose of this work was to examine the effects of various stays in the rucksack (straight stays, bent stays, and no stay) on pressure effects and load distribution to the body. Results showed that wearing the FPV and TV under the rucksack will increase the compressive load on the upper body by 50 to 100 percent, depending on the stay configuration compared with wearing just the TV and Rucksack configuration. Stays bent to conform to the body were the most effective configuration while removal of the stays caused the greatest increase in compressive loads. Edges of the BRP caused multiple peak pressure points of with values on the mannikin of 60 to 110 kPa. These pressure values are expected to considerably exceed the tissue tolerance of skin and underlying muscle and are expected to result in localized skin damage and bruising.

Résumé

Le système de transport de charge HLS comprend la veste pare-éclats (VPE) avec plaques pare-balles (PPB), la veste tactique (VT), le sac à dos et l'ensemble musette et sacs. Tous ces composants ont été conçus de manière à être compatibles. Les charges transportées dans le sac à dos HLS dépassent souvent la charge officielle recommandée de 25 kg et peuvent atteindre près de 45 kg. Dans ces conditions, il est encore plus important d'optimiser la répartition de la charge sur le torse. La présente évaluation visait à déterminer les effets de différents renforts de sac à dos (renforts droits, renforts courbés et aucun renfort) sur la pression et la répartition de la charge sur le corps. Les résultats démontrent qu'en portant la VPE avec PPB sous le sac à dos, la charge de compression exercée sur le haut du corps augmente de 50 à 100 pour cent, selon le type de renfort utilisé, par rapport à la charge exercée en portant uniquement la VT et le sac à dos. La configuration la plus efficace était celle avec renforts courbés pour épouser la forme du corps, et la plus forte augmentation de charge de compression a été mesurée lorsque le sac à dos ne comportait aucun renfort. Les bords des PPB causaient plusieurs points de pression importants dont les valeurs pouvaient atteindre 60 à 110 kPa (mesurés sur le mannequin). Ces pressions sont probablement de beaucoup supérieures au seuil de tolérance de la peau et des muscles sous-jacents, et elles pourraient causer des lésions sur la peau et des ecchymoses.

Executive Summary

The Clothe the Soldier (CTS) load carriage system includes the Tactical Vest (TV), the Rucksack, and a Small Pack System which have been designed to be compatible. This permits various components to be combined to support the operational objectives at hand. In addition to wearing the TV and one of the packs, soldiers are increasingly attempting to wear the Fragmentation Protection Vest (FPV), with Bullet Resistant Plates (BRP) beneath the TV and Rucksack. This work assessed the effects of this practice. The purpose of this work was to examine the effects of various stays in the rucksack (straight stays, bent stays, and no stay) on pressure effects and load distribution to the body. Loads carried in the CTS rucksack often exceed the officially recommended 25 kg and are reported to approach 45 kg. Under these conditions, optimizing load distribution onto the torso becomes even more essential. A Load Distribution Test Mannikin consisting of a human form with two 6 degree of freedom load cells, positioned at T12/L1 and beneath the body, was used to assess the force distribution and pressure effects on the body of the following conditions: 1) TV and Rucksack, stays bent to conform to back as designed, 2) TV, FPV with BRP and Rucksack, stays bent to conform to back, 3) TV, FPV with BRP and Rucksack, straight stays, 4) TV, FPV with BRP and Rucksack with no stays. All were tested with 25 kg in the rucksack.

Results showed that wearing the FPV and BRP under the rucksack will increase the compressive load on the upper body by 50 to 100 percent, depending on the stay configuration compared with wearing just the TV and Rucksack configuration. Stays bent to conform to the body were the most effective configuration while removal of the stays caused the greatest increase in compressive loads. Edges of the BRP caused multiple peak pressure points of with values on the mannikin of 60 to 110 kPa. These pressure values are expected to considerably exceed the tissue tolerance of skin and underlying muscle and are expected to result in localized skin damage and bruising.

Sommaire

Le système de transport de charge HLS comprend la veste tactique (VT), le sac à dos et l'ensemble musette et sacs. Tous ces composants ont été conçus de manière à être compatibles, afin de pouvoir être combinés selon les objectifs opérationnels visés. De plus en plus souvent, les soldats tentent de porter la veste pare-éclats (VPE) avec plaques pare-balles (PPB) en plus de la VT et du sac à dos. La présente évaluation portait sur cette pratique et visait à déterminer les effets de différents renforts de sac à dos (renforts droits, renforts courbés et aucun renfort) sur la pression et la répartition de la charge sur le corps. Les charges transportées dans le sac à dos HLS dépassent souvent la charge officielle recommandée de 25 kg et peuvent atteindre près de 45 kg. Dans ces conditions, il est encore plus important d'optimiser la répartition de la charge sur le torse. Un mannequin d'essai de répartition de la charge de forme humaine, doté de deux cellules de charge à 6 degrés de liberté placées au niveau du disque T12/L1 et sous le corps, a été utilisé pour évaluer la répartition de la charge et la pression sur le corps des combinaisons de composants suivantes : 1) VT et sac à dos avec renforts courbés pour épouser la forme du dos, 2) VT, VPE avec PPB et sac à dos avec renforts courbés pour épouser la forme du dos, 3) VT, VPE avec PPB et sac à dos avec renforts droits, 4) VT, VPE avec PPB et sac à dos sans renforts. Les essais ont tous été effectués avec une charge de 25 kg placée dans le sac à dos.

Les résultats démontrent qu'en portant la VPE avec PPB sous le sac à dos, la charge de compression exercée sur le haut du corps augmente de 50 à 100 pour cent, selon le type de renfort utilisé, par rapport à la charge exercée en portant uniquement la VT et le sac à dos. La configuration la plus efficace était celle avec renforts courbés pour épouser la forme du corps, et la plus forte augmentation de charge de compression a été mesurée lorsque le sac à dos ne comportait aucun renfort. Les bords des PPB causaient plusieurs points de pression importants dont les valeurs pouvaient atteindre 60 à 110 kPa (mesurés sur le mannequin). Ces pressions sont probablement de beaucoup supérieures au seuil de tolérance de la peau et des muscles sous-jacents et elles pourraient causer des lésions sur la peau et des ecchymoses.

Table of Contents

List of Figures

List of Tables

1.0 Fragmentation Protection Vest and Stay Effect on Load Distribution

1.1 Purpose

The Clothe the Soldier (CTS) load carriage system includes the Tactical Vest (TV), the Rucksack, and a Small Pack System which have been designed to be compatible. This permits various components to be combined to support the operational objectives at hand. With the enhanced threat levels that soldiers are experiencing on operations, soldiers are now wearing a Fragmentation Protection Vest (FPV) with Bullet Resistant Plates (BRP) beneath the TV and Rucksack.

The purpose of this work was to assess the effects of various stays (straight-stay, bent-stay, and no-stay) on the load distribution to the body, especially the load distribution to the upper torso, when wearing the FPV with BRP beneath the TV and Rucksack. Additionally, loads carried in the CTS rucksack often exceed the officially recommended 25 kg and are reported to approach 45 kg. Under these conditions, optimizing load distribution onto the torso becomes even more essential.

2.0 Methods

Four configurations were tested to determine the effects of various stays (straight-stay, bent-stay, and no-stay) on the load distribution to the body when wearing the FPV with BRP beneath the TV and Rucksack. The configurations were: TV with bent-stay rucksack (baseline condition); FPV with BRP, TV, and straight-stay rucksack; FPV with BRP, TV, and bent-stay rucksack; and FPV with BRP, TV, and no-stay rucksack. The loads in the TV and rucksack are described below.

Tactical Vest Load

Total mass of loaded TV was 15.24 kg (33.6 lb), consisting of:
(4) C7 mags,
(2) Fragmentation grenades,
(2) M18 smoke grenades,
(1) C9 drum,
(1) Water bottle and canteen cup
(1) Bayonet
Plus additional steel and lead blocks in both front lower pouches, 2.5 kg per side.

Rucksack Payload

The 25 kg payload was constructed of a single section, consisting of 5 steel plates secured within a glued rigid Styrofoam™ box (Figure 1). Total mass of the payload was 25.2 kg (55.1 lb). The steel plates were placed such that the resultant center of mass was at the center of the rucksack volume.

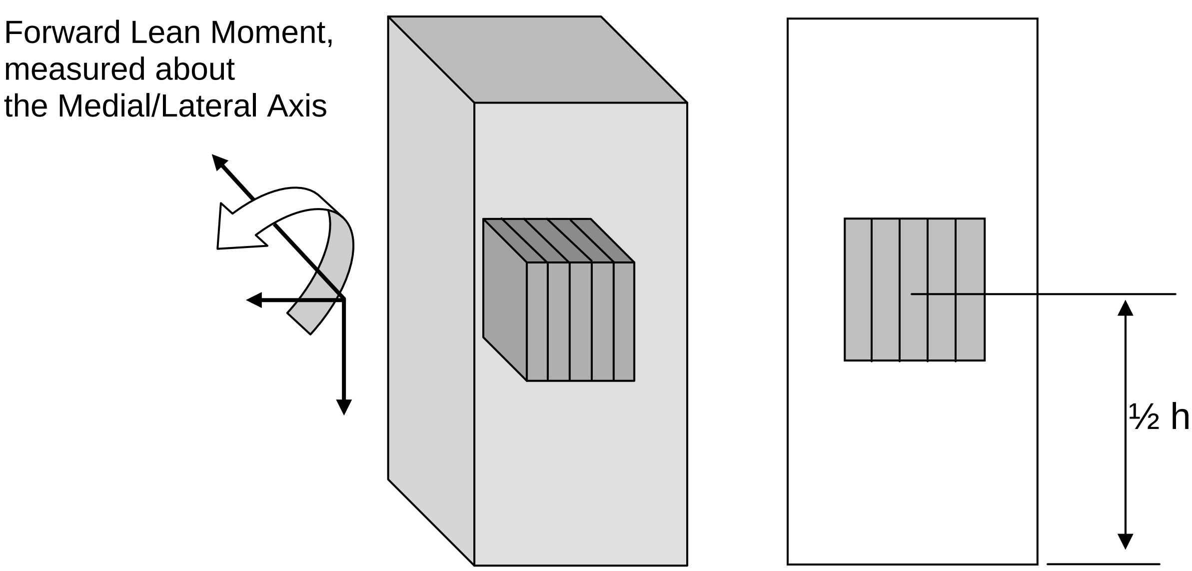


Figure 1. Schematic of the Rucksack Payload used for Load Distribution testing

2.1 Description of Load Distribution Mannikin

All testing was conducted using the Load Distribution Mannikin developed under DSS Contract # W7711-4-7225/01-XSE, titled *Research and Development of an Advanced Personal Load Carriage System (Phase I-D).* The device consists of a 50 percentile male mannikin form that has been instrumented with a six degree of freedom load cell (AMTI Incorporated, MC5-2500) at the approximate height of T12/L1. As shown below in Figure 2, the mannikin form is mounted on a vice that permits forward rotation of the entire torso at the base and the entire apparatus rests on a six degree of freedom force plate at floor level. Using this device, the load carried by the shoulders and upper body can be resolved separately from the load carried by the hips and lower body.

Figure 2. Load Distribution Tester

Comparing the two loads cell outputs permits solution of the upper and lower body loadings.

2.2 Load Distribution Test Protocol

All configurations were tested using identical instrumentation. The floor level force plate was a portable AMTII Accupower® System, model ACP. Care was taken to ensure that the portable force plate was stable and level at all times. The Accupower force plate was re-zeroed prior to testing each configuration. The load cell at T12/L1 was an AMTII MC5-6-2500, amplified with a Modular 600 Multi-channel Transducer Amplifier, RDP Group™. Data was recorded at 100 Hz for 10 seconds for both load cells and stored for post processing. For each configuration, the same protocol was followed.

1. Ensure the force plate is stable and level.
2. Zero the force plate.
3. Position the Load Distribution Mannikin on the force plate, aligning the X and Y axes of the two load cells using the alignment markings.
4. Position the FPV on the torso if required. Position of the lap joints was marked on the Velcro® on the front of the shoulders and at the sides to ensure reproducibility.
5. Position the TV on the mannikin, location of the TV shoulders was marked to ensure reproducible placement.
6. Position the loaded rucksack onto the FPV (or onto the TV). The position of the waist belt was marked on the mannikin surface and held constant for all testing.
7. Rucksack straps were tightened to the same values (+/- 5 N) as those used for the dynamic testing (Table 1).

2.3 Load Distribution Strap Force Settings

Tension of the rucksack straps used during the load distribution testing and are summarised in Table 1 below.

Table 1. Load Distribution Strap Tensions for Testing

1. Shoulder Strap	22 N
2. Waist Belt	32 N
3. Hip Stabilizer	32 N *
4. Sternum Strap	18 N *
5. Load Lifter	20 N *

* Tension value estimate, these are estimated residual tensions when pulled with 15 lbf, 4 lbf and 5 lbf values on a Chatillon pull gauge respectively.

Figure 3. CTS Rucksack worn with Tactical Vest and Fragmentation Protection Vest

2.4 Skin Contact Pressures

An F-Scan™ pressure sensor system (Tekscan Incorporated) was used to acquire contact pressure data on the manikin skin over the anterior shoulder, posterior shoulder, scapula, hips, upper and lower back regions. The F-Scan™ system uses a matrix of force sensitive resistors, arranged in a rectangular pattern and contained between two flexible sheets. At full size, there are 96 force sensitive resistors spaced over a region 206 mm by 76 mm. When the thin polymer in each element is compressed, there is a change in the element. This change is sensed by system software and is recorded as a load normal to the sensor surface, based on individual calibration for each sensor. Information is transferred to the computer through a signal processing unit and cable to a computer card. This information can be replayed in "movie" format, which can give a dynamic measurement of force, average and peak pressures, active area, or duration of contact. Previous testing at Queen's University (Stevenson et al., 1996, Hadcock, 2002) has found the F-Scan™ system standard error of the mean to be 9.6% for average pressures and 14% for peak pressures. Also, use of the sensors on a curved surface lead to a 9% standard error of the mean for average pressure results (MacNeil, 1996).

For this testing, pressure data were reported in terms of a peak dynamic pressures (kPa) and the average pressure over all active cells of the sensors (kPa) in the anatomical areas of interest. Research has shown that blood occlusion can occur when tissues are loaded at an average pressure of 14 kPa for 8 hours[1]. Average skin contact pressures of 20 kPa have also been associated with discomfort in 95 % of a test sample.

[1] Holloway, JA., Daly, CH., Kennedy, D., and J. Chimoskey. (1976). Effects of external pressure loading on human skin blood flow. . *Journal of Applied Physiology* **40**: 596-600.

3.0 Results

Results of the load distribution testing are shown below in Figures 4, 5 and 6. Forces are reported in Newtons (N) and moments in N.m. All configurations were compared to the baseline condition of tactical vest with bent-stay rucksack, no fragmentation vest (BS NF) to quantify the effect of the equipment combinations. The error bars indicated represent +/- 2 standard deviations of the recorded data. Differences greater than the range of the error bars are considered to be significantly different.

3.1 Load Distribution Results

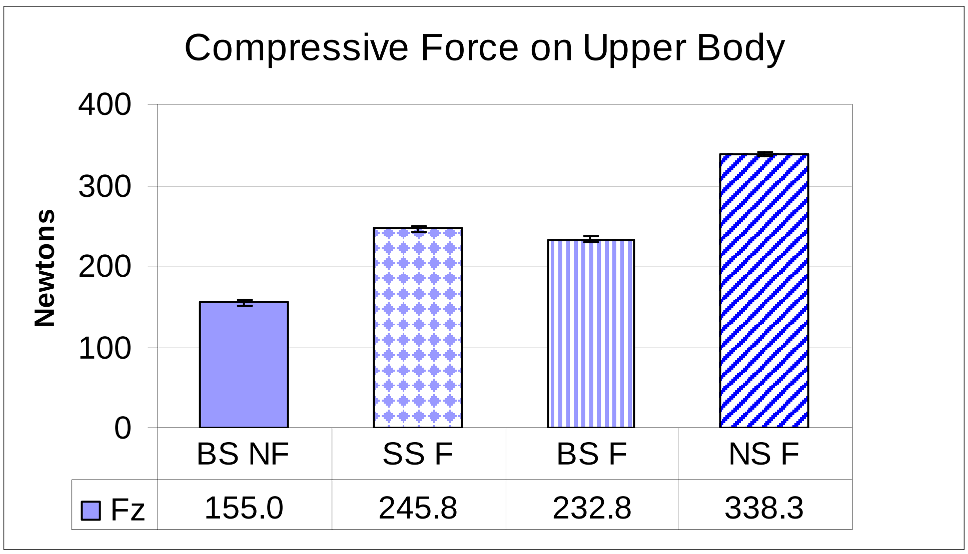


Figure 4. Compressive Force on the Upper Body and Spine.

BS NF - Bent Stay, No Frag (baseline condition).
SS F - Straight Stay, Frag, the CTS rucksack with bent stays.
BS F - Bent Stay, Frag, the CTS rucksack with straight stays.
ND F- No Stay, Frag, the CTS rucksack with stays removed.

The increasing weight of equipment is apparent in the increase in the vertical compressive force experienced by the spine when the baseline condition (BS NF) is compared to the other three configurations. Compressive load increased by 78 to 183 N in the other configurations with the fragmentation vest and ballistic plates. The utility of the stay in shifting load directly onto the hip is apparent; the no stay configuration (NS F) showed approximately 100 N more compressive load than the configurations with stays, and double compression experienced in the baseline condition.

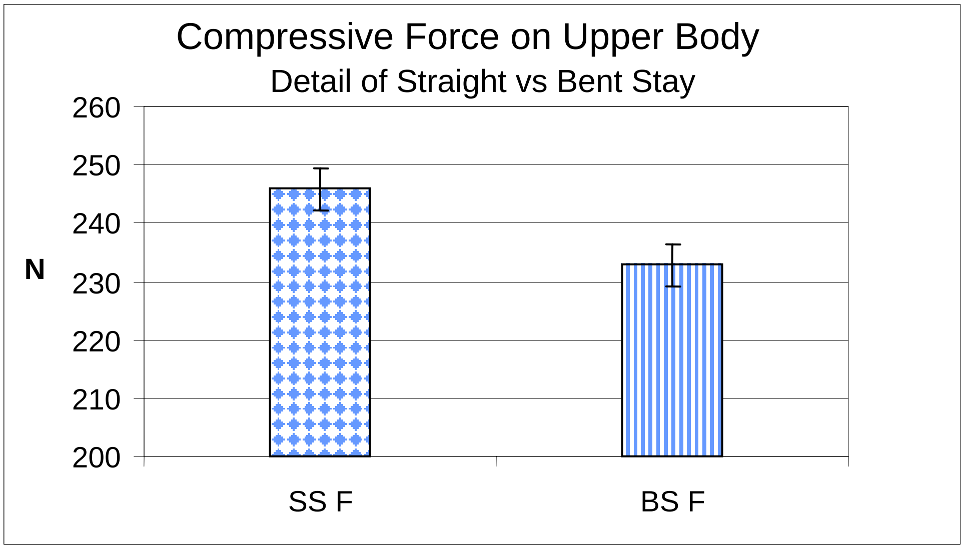


Figure 5. Compressive force on the Upper Torso for Straight versus Bent Stay
Straight Stay with Frag Vest: **SS F**; Bent Stay with Frag Vest: **BS F**

Figure 5 highlights the significant effect of contouring the stay to follow the shape of the back. The bent stay is more effective at transferring load directly to the hip.

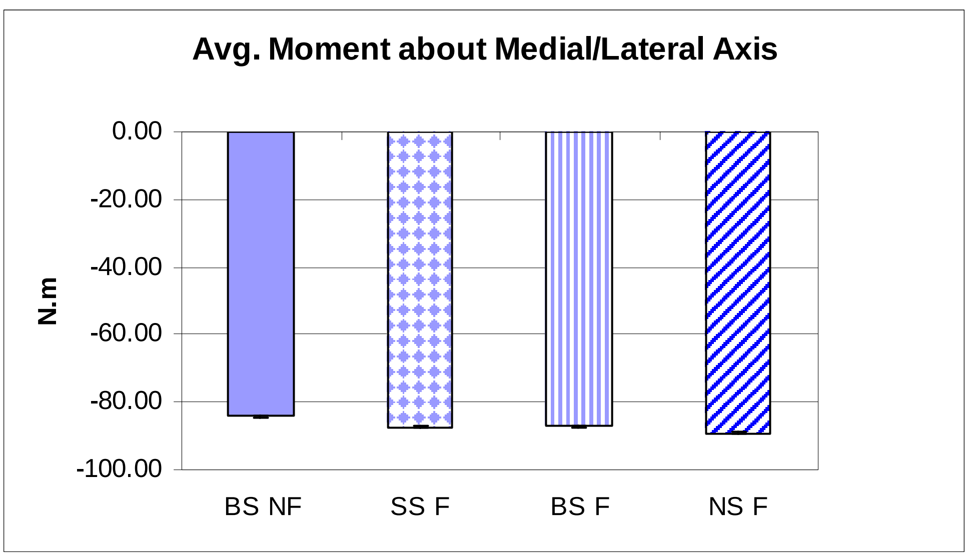


Figure 6. Effect of Stays on the Forward Lean Moment

BS NF - Bent Stay, No Frag (baseline condition).
SS F - Straight Stay, Frag, the CTS rucksack with bent stays.
BS F - Bent Stay, Frag, the CTS rucksack with straight stays.
ND F- No Stay, Frag, the CTS rucksack with stays removed.

Moment about the medial/lateral axis is defined as positive when it tends to make someone lean forward and negative when it tends to make someone lean backward. Figure 6 summarizes the combined effect of the stays and the effect of layers of equipment kit that is positioned between the body and the mass in the rucksack. As the mass in the rucksack is pushed farther out from the back, the moment becomes increasingly negative. Comparing the BS NF to the BS F condition shows this effect. When the straight stay condition SS F is compared to the bent stay BS F configuration, no difference is seen between the bent versus a straight stay. In other words, the change in the position of the rucksack load due to the presence of the Frag vest causes the increase in negative moment. Finally, comparing the two farthest right columns indicates that the presence of the stay does help control the location of the centre of mass of the rucksack. With no stays, the load apparently sags farther away from the body – increasing the negative moment slightly.

3.2 Pressure Results

A total of 15 locations on the torso were monitored for contact pressure. Four of these sites were found to have insignificant loading and these are not included in this report. Figure 7 shows the locations of the FScan sensors and indicates with red markers the locations of the peak pressures where recorded pressure exceeded 34 kPa locally. Table 2 is a summary of approximate location, magnitude and cause of these peak pressures. Figure 8 provides a comparison of peak pressures for all four configurations at locations identified in Figure 7 and Table 2. Sensor location 6 showed a trivial amount of contact pressure and these data were subsequently was not reported. Similarly, Figure 9 a and b is a plot of the location and magnitude of the average pressures recorded for all monitored sites in the four configurations tested. Peak pressures are associated with local tissue damage while average pressures are typically associated with more general fatigue of that body region. The pressure data file for the NS F condition at location 11 was accidentally overwritten and subsequently is not shown in Figures 8b and 9b.

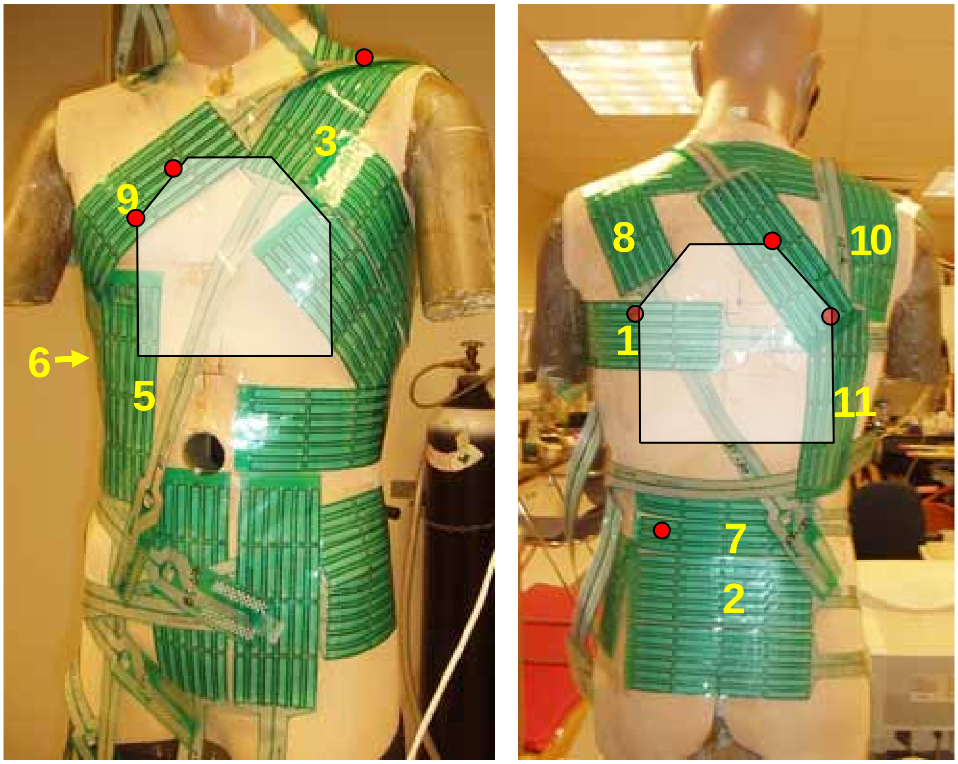
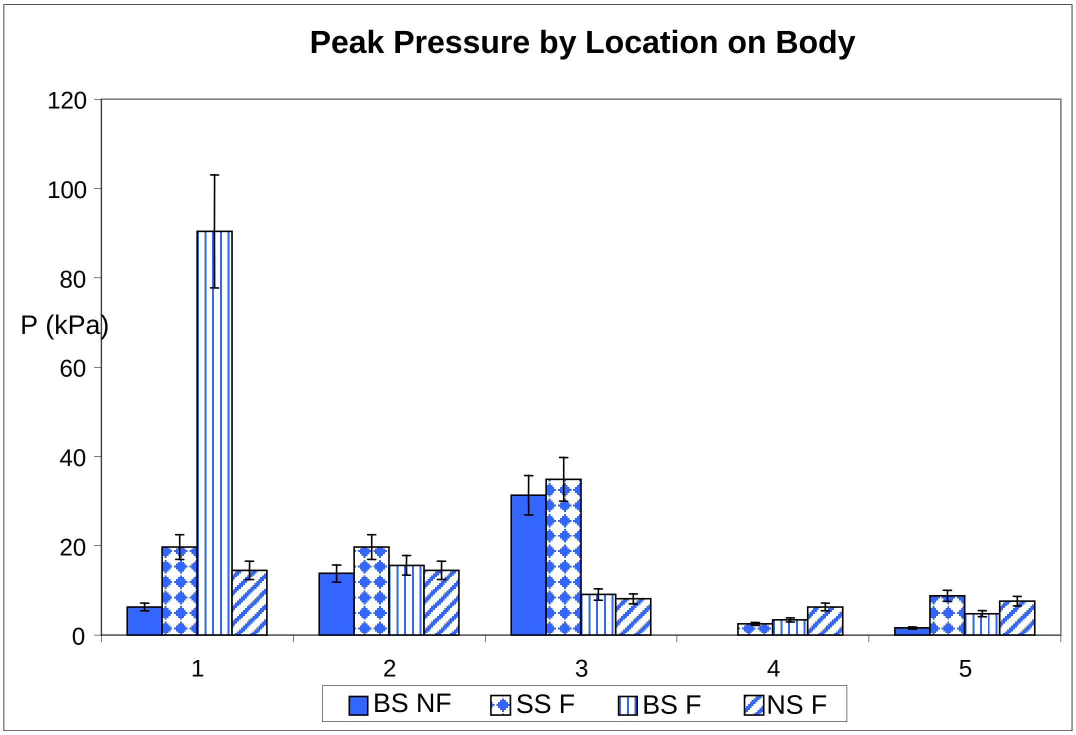


Figure 7. Pressure Sensor Locations

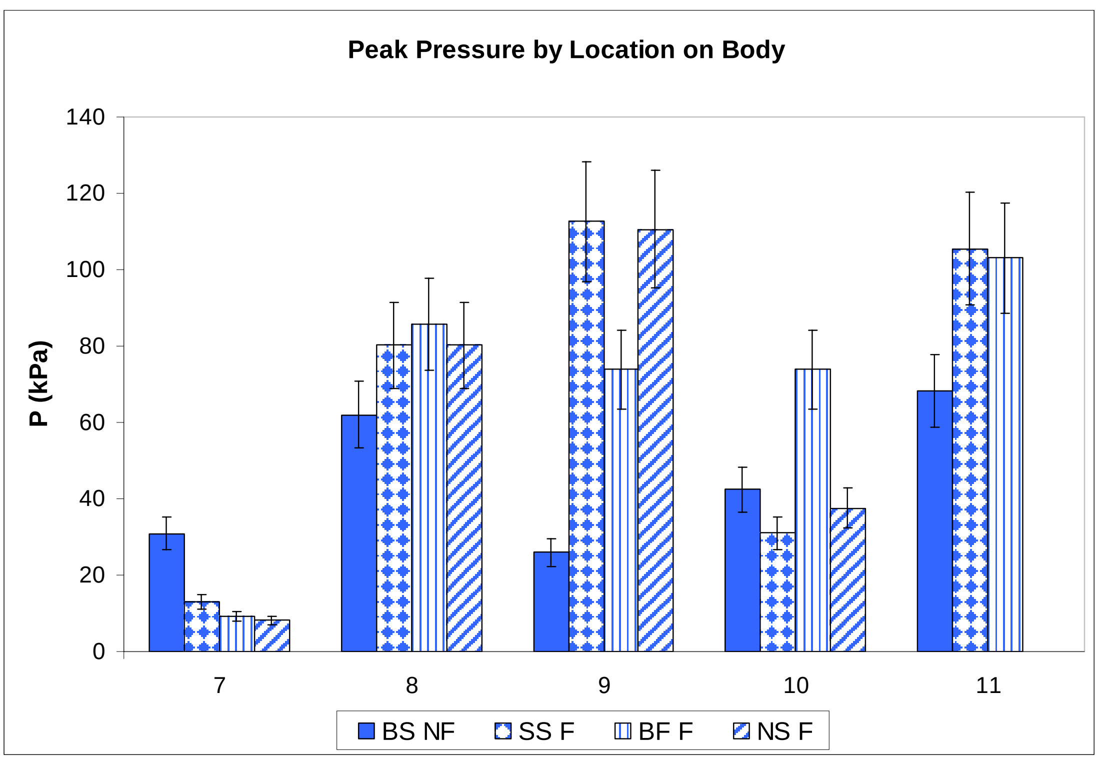
Location of peak pressures greater than 34 kPa are indicated with red markers. The approximate position of the ballistic plates is also shown.

Table 2. Description of Peak Pressure Causes

Config.	Location	Peak	Cause
Bent Stay No Frag	8	60 kPa	Bar tack on daisy chain on TV shoulder caught under Ruck strap. Soldier could adjust.
	10	42 kPa	Immediately under load lifter buckle at top of shoulder
	11	68 kPa	Metal fit adjust buckle on TV - under padding of Ruck. Soldier may be able to adjust.
Straight Stay Frag	1	>40 kPa	Corner of ballistic plate
	3	35 kPa	Shoulder flap of Frag Vest trapped under Ruck strap. Soldier could adjust.
	8	80 kPa	Inclined edge of ballistic plate
	9	113 kPa	Inclined edge and corner of ballistic plate
	11	105 kPa	Vertical edge and corner of ballistic plate
Bent Stay Frag	1	90 kPa	Corner of ballistic plate
	8	86 kPa	Inclined edge of ballistic plate
	9	74 kPa	Vertical edge and corner of ballistic plate
	11	103 kPa	Vertical edge and corner of ballistic plate
No Stay Frag	1	74 kPa	Corner of ballistic plate
	8	80 kPa	Inclined edge of ballistic plate
	9	111 kPa	Vertical edge and corner of ballistic plate
	11	n/a kPa	Corrupted data file



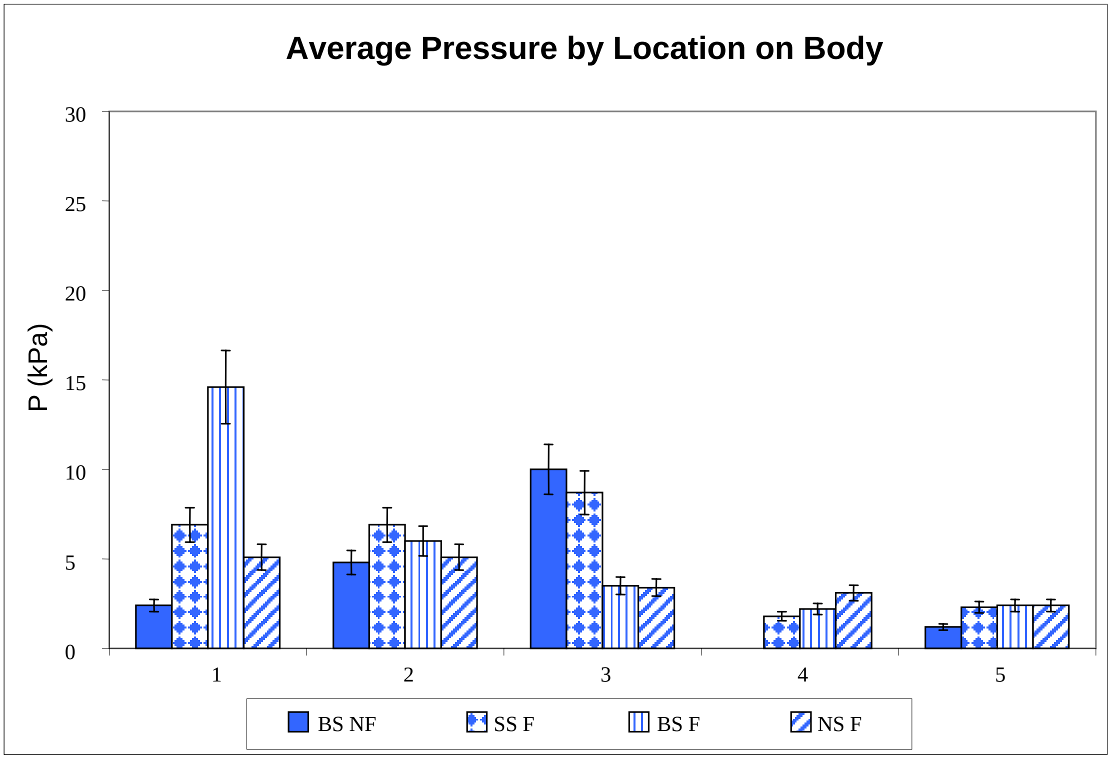
a)



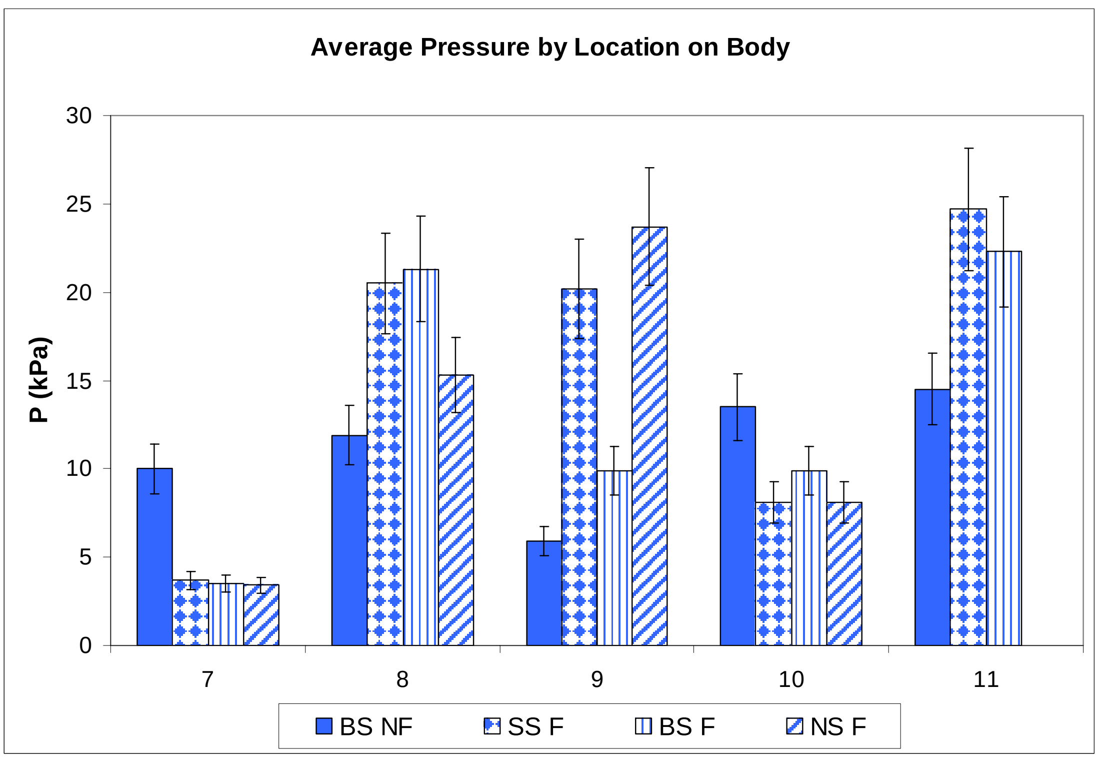
b)

Figure 8 a & b. Peak pressure on the body at all monitored sites.

These values correspond to the locations experiencing the highest local contact pressure. Maximum acceptable peak pressure is considered to be 34 kPa. Error bars show +/- 14% which is the tested accuracy of the pressure sensors. Values are considered to be significantly different if the error bars do not overlap. No data for NS F, #11.



a)



b)

Figure 9 a & b. Average contact pressure on the body at all monitored sites.

Average pressure is total force on each sensor divided by contact area. Average pressures should be less than 20 kPa for continuous exposure. Error bars show +/-14%, the measured FScan sensor accuracy.

Figure 10. Lateral Migration of Shoulder Straps

Figure 11. Congestion in the Armpit Area

4.0 Discussion of Load Distribution Results

The TV and the rucksack have been designed to be worn together and consequently this results in minimal conflict between these two items. However, with the increased threat levels that soldiers are experiencing on operations they are now wearing their FPV with BRP under their TV and rucksack.

When the TV and FPV with BRP are worn under the rucksack, several general observations can be made. In all cases, the additional bulk of the fragmentation vest took up additional rucksack shoulder strap length, causing the shoulder straps to appear short (Figure 10). This in turn caused the shoulder strap tightening knobs to move upwards into the armpit area (Figure 11). The considerable bulk of the ballistic plates and Kevlar under the TV encourage the shoulder strap to move laterally into the area of the brachial artery and brachial nerve in the axilla. In situations where the shoulder strap is already somewhat short for the individual, the fittings at the end of the shoulder strap will likely be the part of the strap in contact here.

4.1 Discussion of Load distribution to the Torso

In the baseline condition, the total load carried on the body is 396.3 N (40.4 kg). Adding the fragmentation vest, places approximately 90 N directly onto the shoulders. This brings the total load to 496.3N. Figure 4 clearly shows the impact of this additional weight on the upper body compressive load as the three FPV conditions all show a significant increase. In the baseline condition, more than half the load is transferred directly to the lower body with the upper body 'shouldering' 155 N of the 396.3 N. This translates into a 60/40 split of the load between hips and shoulders. As the load in the rucksack increases, to perhaps 445N (45 kg), this proportional split can likely be maintained. When the FPV is worn, the upper body 'shoulders' 233 to 338 N of the 496.3 N carried. Of the three configurations with the FPV, the bent stay was the most effective at unloading the shoulder, although the compressive load on the shoulders still increased by a factor of 1.5 over the baseline condition. The straight stay and the no stay configurations showed an increase in the compressive load of 1.6 and 2.8 times the baseline condition respectively. Although the compressive load increased, the spine is well designed to support compression. These values are not excessive in terms of the spines capacity to withstand compression. However, the spine is more vulnerable to off axis loading and as loads increase, the most dangerous activities may be during donning, doffing or during rapid unexpected manoeuvres when the larger inertial forces have to be controlled.

Also apparent in Figure 4 is the increased compression load in the no stay condition. This highlights the effectiveness of the stays in transferring the load from the shoulders directly onto the lower body via the hip belt. Since the shoulder girdle is essentially a cantilever stabilized by multiple muscle groups, in particular the trapezius and rhomboids, the additional weight on the shoulders will require additional muscular effort to support and stabilize this structure.

4.2 Discussion of Pressure distribution on to the Torso

Figure 5 shows the difference between the straight stay and the bent stay tests; here the bent stay appears slightly more efficient at unloading the shoulders by 13 N (accuracy +/-2N). Finally, when forward lean hip moment is examined in Figure 6, the effect of the FPV was inconsequential. The weight of the FPV is distributed about the torso and hangs directly on the shoulders, minimizing the effect. Small variations in the moment will be accommodated by slight adjustments in the forward lean of the torso.

In all cases the peak pressures experienced while wearing the baseline configuration of rucksack and TV only, were lower than those experienced while wearing the FPV. The FPV has some protective effect by placing multiple layers of Kevlar® between the shoulder straps and the body, effectively distributing the load. As a result, any effect of discontinuities like multiple layers at seams or entrapped buckles is reduced. In all cases though, peak pressures under the FPV were due to the edges of the ballistic plates digging into the body, both at the front in the shoulder area as well as near the clavicle, and on the upper back. Peak pressures recorded at the points identified in Figure 8 for the FPV, were well in excess of values recommended for extended exposure (34 kPa) and ranged from 80 to 111 kPa.

The average pressure plots shown in Figures 9a and 9b summarize the general effect that the FPV has on the pressures experienced on the body. The high average pressures seen in locations 8, 9 and 11 are partially due to the extremely high peak pressures in these regions. The shielding effect discussed previously is illustrated in location 7 of Figure 9b. In this case, the Kevlar minimized the effect of a local buckle on the TV and distributed the load better.

5.0 Conclusions and Recommendations

Analysis of the load distribution results leads to the following conclusions:

1. The straight down compressive force on the upper body was increased by +90 N in all cases where the FPV with BRP was worn.
2. The increase is at least 1.5 (i.e.1.5 to 2.8) times the compressive load experienced in the baseline condition.
3. The upper body carries a greater portion of the load when the FPV with BRP was worn.
4. Stays were still able to transfer a portion of the rucksack load directly to the hips, even when worn with the FPV and BRP.
5. The bent stays were more effective at unloading the shoulders than the straight stay or no stay conditions.
6. The no stay condition disproportionably loaded the shoulders, shifting 95 N of the rucksack load onto the shoulders, in addition to the 90 N weight of the FPV.
7. The effect of the FPV with BRP weight had a minimal effect on the forward lean moment.

Analysis of the pressure distribution results leads to the following conclusions:

8. The multiple layers of the FPV have some ability to equalize pressure distributions onto the body by attenuating discontinuities in geometry.
9. Peak pressures under the corners and edges of the ballistic plates greatly exceeded recommended contact pressures for long-term exposure. This occurred at multiple locations around the edges of the plates in all conditions when they were worn under the rucksack.

In summary, the fragmentation protection vest with ballistic plates increases the compressive load on the spine and adds to the inertia of the soldier. Even with the fragmentation protection vest on, the stays, particularly bent stays, were effective in transferring the rucksack load directly onto the hips. Finally, the edges of the ballistic plates caused multiple high pressure points all of which are expected to cause discomfort and in some cases will likely cause bruising, blisters and other tissue damage.

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7.0 Appendix A - Load Carriage Simulator Description

7.1 Torso Specifications and Preparation

A family of four anthropometric mannikins (5^{th} and 50^{th} percentile females, and 50^{th} and 95^{th} percentile males, as defined by Safework™ anthropometric software) were constructed for LC simulator testing. Each mannikin was comprised of a head and trunk section, with arms truncated in the mid-humeral region and legs extending to just below the buttocks.

These human models consisted of a fibreglass outer shell with expandable poured polyurethane foam filling. Proper mass distribution was achieved by thoroughly mixing aggregate with the interior foam. A vertical cylindrical cavity was created in each mannikin to allow for mounting of a six degree-of-freedom load cell. In each case, the neutral axis of the load cell was positioned at the approximate location of the mannikin's hips. This load cell was further mounted on a single axis articulating vice, which permitted the mannikin and LC system to be placed in a balanced anterior body lean position for load carriage. Finally, the surface of each mannikin was covered with a 5 mm thickness of Bocklite™, a synthetic skin-like material used on prosthetics, to approximate the compressive response of human skin over bone.

7.2 Test Protocol

The LC Simulator consists of the previously described rigid mannikin, mounted on a programmable displacement platform. This platform rests on three air cylinders which allow vertical motion as well as rotation about the x (anterior/posterior) and y (medial/lateral) axes. A computer controlled vertical displacement pattern (+/- 25.4 mm amplitude, 1.8 Hz frequency) simulates marching, and linear displacement transducers provide positional information for the control system. Feedback control is accomplished by varying the differential pressure across each cylinder face.

Each LC mannikin was loaded with the payload, positioned on the simulator and properly adjusted. A standard LC Sim test is comprised of multiple intervals of 120 seconds of simulated walking was performed. The sampling rate for all data collection is 55 Hz and the duration is 10 seconds (minimum). Outcome measures from the LC Sim test consist of; the relative displacement between mannikin and the LC system; contact pressures on the shoulders, upper back, and lower back; and hip reaction forces and moments.

7.3 Relative Displacement of LC System and Torso

An electromagnetic position tracking system (Fastrak™ by Polhemus Incorporated) was used to provide three dimensional displacement data. The source for the Fastrak™ was affixed with nylon screws to the underside of the left arm of the mannikin. All compression straps were tightened securely. A Fastrak™ sensor was then attached to the upper surface of a polystyrene insert. This insert was placed on top of the payload and held in place with 2 inch long steel pins driven through the four sides of the rucksack into the polystyrene block. The inner liner and the lid of the rucksack were tightened securely over the payload and insert. Displacement data, for the payload with respect to the source, was recorded for 10 seconds at 55 Hz over the duration of the test. The payload and insert were not disturbed between the with/without abdominal plate tests thus allowing a direct comparison of the relative displacement of the payload under the two conditions.

7.4 Reaction Forces and Moments

Ground reaction forces and moments were collected using a 6 degree-of-freedom load cell (AMTI Incorporated) based on a body fixed coordinate system located at the hip and oriented along the long axis of the trunk. The outcomes from this instrumentation were reported as reaction forces in the Fx (forward and back), Fy (side to side), and Fz (up and down) directions.

Reported reaction forces were normalized by dividing them by the payload carried in the load carriage system. The resultant *normalized* values were expressed as Nm/kg for moments and N/kg for forces. A normalized force of 9.81 N/kg indicated a force of 9.81 N for each kilogram of load carried.

7.5 Skin Contact Pressures

An F-Scan™ pressure sensor system (Tekscan Incorporated) was used to acquire contact pressure data on the mannikin skin over the anterior shoulder, posterior shoulder, scapula and low back region. Figure 2.2-2 shows the orientation of the F-Scan™ 9810 pressure sensors, which were affixed to the mannikin with a non-permanent adhesive. The F-Scan™ system uses a matrix of force sensitive resistors, which are arranged in a rectangular pattern and contained between two flexible polyester plastic sheets. At full size, there are 96 force sensitive resistors spaced over a region 206 mm by 76 mm. When the thin polymer in each element is compressed, there is a change in the element. This change is sensed by system software and is recorded as a load normal to the sensor surface, based on individual calibration for each sensor. Information is transferred to the computer through a signal processing unit and cable to a computer card. This information can be replayed in "movie" format, which can give a dynamic measurement of force, average and peak pressures, active area, or duration of contact. Previous testing at Queen's (Stevenson et al., 1996, Hadcock, 2002) has found the F-Scan™ system standard error of the mean to be 9.6 % for average pressures and 14 % for peak pressures. Also, use of the sensors on a curved surface leads to a 9% standard error of the mean for average pressure results (MacNeil, 1996).

For this testing, pressure data were reported in terms of peak dynamic pressures (kPa) and average pressure over all active cells of the sensors (kPa) in the anatomical areas of interest.

7.6 Strap Forces

During the setup phase of the LC Simulator testing, strap force tension transducers were placed in-line in both shoulder straps and the left half of the waist belt, free of any hip/kidney padding. Attachment of the transducers was accomplished by placing a pin through an attachment ring in the end of the carrier material of each transducer, ensuring that all tension in the strap was transmitted through the transducer. Output from the force transducers was amplified by a Keithley MetraByte DATAQ system (Keithley MetraByte Instruments Incorporated) and recorded digitally as part of the test record. Initial settings of 60 +/- 5 N in the shoulder straps and 90 +/- 5 N in the waist strap were used for all load carriage trials. The force transducers were constructed with four foil style strain gauges, attached in a full Wheatstone bridge configuration to a rounded I-shaped 6061-T6 aluminium carrier with a length of 38.00 mm and thickness of 1.14 mm. Static testing of the transducers showed they were highly linear (r^2 >0.9995) with a small standard error (<0.01 V).

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Assessment of the effect of No Stay, Bent Stay or Straight Stay when the Clothe the Soldier Rucksack is worn with the Fragmentation Vest (U)
Évaluation de l’effet des différentes configurations de renforts (aucun renfort, renfort courbé ou renfort droit) lors du port du sac à dos HLS avec la veste pare−éclats (U)

4. AUTHORS (First name, middle initial and last name. If military, show rank, e.g. Maj. John E. Doe.)

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(U) The Clothe the Soldier (CTS) load carriage system includes the Fragmentation Protection Vest (FPV) with Bullet Resistant Plates (BRP), Tactical Vest (TV), the Rucksack, and a Small Pack System which have been designed to be compatible. Loads carried in the CTS rucksack often exceed the officially recommended 25 kg and are reported to approach 45 kg. Under these conditions, optimizing load distribution onto the torso becomes even more essential. The purpose of this work was to examine the effects of various stays in the rucksack (straight stays, bent stays, and no stay) on pressure effects and load distribution to the body. Results showed that wearing the FPV and TV under the rucksack will increase the compressive load on the upper body by 50 to 100 percent, depending on the stay configuration compared with wearing just the TV and Rucksack configuration. Stays bent to conform to the body were the most effective configuration while removal of the stays caused the greatest increase in compressive loads. Edges of the BRP caused multiple peak pressure points of with values on the mannikin of 60 to 110 kPa. These pressure values are expected to considerably exceed the tissue tolerance of skin and underlying muscle and are expected to result in localized skin damage and bruising.

(U) Le système de transport de charge HLS comprend la veste pare−éclats (VPE) avec plaques pare−balles (PPB), la veste tactique (VT), le sac à dos et l’ensemble musette et sacs. Tous ces composants ont été conçus de manière à être compatibles. Les charges transportées dans le sac à dos HLS dépassent souvent la charge officielle recommandée de 25 kg et peuvent atteindre près de 45 kg. Dans ces conditions, il est encore plus important d’optimiser la répartition de la charge sur le torse. La présente évaluation visait à déterminer les effets de différents renforts de sac à dos (renforts droits, renforts courbés et aucun renfort) sur la pression et la répartition de la charge sur le corps. Les résultats démontrent qu’en portant la VPE avec PPB sous le sac à dos, la charge de compression exercée sur le haut du corps augmente de 50 à 100 pour cent, selon le type de renfort utilisé, par rapport à la charge exercée en portant uniquement la VT et le sac à dos. La configuration la plus efficace était celle avec renforts courbés pour épouser la forme du corps, et la plus forte augmentation de charge de compression a été mesurée lorsque le sac à dos ne comportait aucun renfort. Les bords des PPB causaient plusieurs points de pression importants dont les valeurs pouvaient atteindre 60 à 110 kPa (mesurés sur le mannequin). Ces pressions sont probablement de beaucoup supérieures au seuil de tolérance de la peau et des muscles sous−jacents, et elles pourraient causer des lésions sur la peau et des ecchymoses.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

(U) Clothe the Soldier; CTS; Load carriage system; pressure measurement system; load carriage simulator; load distribution; rucksack; fragmentation vest